NACA

RESEARCH MEMORANDUM

TESTS OF THE NACA 0010-1.50 40/1.051 AIRFOIL SECTION AT HIGH SUBSONIC MACH NUMBERS

By Albert D. Hemenover

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE
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SUMMARY

Aerodynamic characteristics of the NACA 0010-1.50 40/1.051 airfoil section have been determined from wind-tunnel tests at Mach numbers from 0.3 to 0.9. The corresponding Reynolds number variation was from approximately 1×10^6 to 2×10^6. These results for an airfoil with a leading-edge radius of 1.50 percent of the chord are compared with those of a previous investigation of the effects of leading-edge-radius variation from 0.27 to 1.10 percent of the chord on the characteristics of a 10-percent-thick, symmetrical airfoil section at high subsonic Mach numbers.

The comparison indicates small increases of the Mach numbers for lift and drag divergence at low lift coefficients for the section with the largest leading-edge radius.

INTRODUCTION

In reference 1, the effects of systematic reduction of the leading-edge radius on the variation with Mach number of the aerodynamic characteristics of a 10-percent-thick, symmetrical airfoil section were reported. To examine the effects of an increase in leading-edge radius for the same airfoil section, the present investigation was undertaken in the Ames 1- by 3-1/2-foot high-speed wind tunnel. The airfoil is of the modified NACA four-digit series (see ref. 2), with maximum thickness at the 40-percent-chord position and with a trailing-edge angle of 12°. In the present instance the airfoil leading-edge radius is 1.50 percent of the chord; whereas in reference 1 the radii were 1.10, 0.70, and 0.27 percent of the chord. To facilitate comparison, the results of reference 1 are reproduced in the present paper.

NOTATION

a_o	section lift-curve slope at zero lift coefficient, per deg
c_d	section drag coefficient
c_l	section lift coefficient
$c_{l_{max}}$	maximum section lift coefficient
$c_{m_{c/4}}$	section pitching-moment coefficient about the quarter-chord point
M	Mach number
M_d	drag-divergence Mach number, defined as the Mach number at which $\left(\frac{dc_d}{dM}\right)_{\alpha_o = \text{constant}} = 0.1$
M_l	lift-divergence Mach number, defined as the Mach number corresponding to the initial inflection point on curves of section lift coefficient as a function of Mach number at constant angle of attack
R	Reynolds number
α_o	section angle of attack, deg

AIRFOIL DESIGNATION

The airfoil section of the present investigation is designated as: NACA 0010-1.50 40/1.051. The first digit of the airfoil designation indicates the camber in percent of the chord; the second, the position of the camber in tenths of the chord from the leading edge; and the third and fourth, the maximum thickness in percent of the chord. The decimal number following the dash is the leading-edge-radius index; the leading-edge radius as a fraction of the airfoil chord is given by the product of the radius index and the square of the thickness-chord ratio. A radius index of 1.10 is standard for the NACA four-digit-series airfoil sections. The two digits immediately preceding the slant represent the position of maximum thickness in percent of the chord from the leading edge. The last decimal number is the trailing-edge-angle index, the angle being twice the arc tangent of the product of the angle index and the thickness-chord ratio.

The coordinates of the airfoil investigated are given in table I. This airfoil profile is illustrated in figure 1 along with those of reference 1 to show the influence of leading-edge radius on profile shape.

APPARATUS AND TESTS

The test was conducted in the Ames 1- by 3-1/2-foot high-speed wind tunnel, a low-turbulence two-dimensional-flow wind tunnel.

The airfoil model was of 6-inch chord and was constructed of aluminum alloy. The model completely spanned the 1-foot dimension of the tunnel test section. Contoured sponge-rubber gaskets compressed between the model ends and the tunnel walls preserved two-dimensional flow by preventing end leakage.

Measurements of lift, drag, and quarter-chord pitching moment were made simultaneously at Mach numbers from 0.3 to approximately 0.9 for the model at angles of attack increasing by increments of 1° or 2° from -2° to 12°. This range of angles was sufficient to encompass negative lift at all Mach numbers and the lift stall up to a Mach number of 0.8. The Reynolds number variation with Mach number for the test is illustrated in figure 2.

Lift forces and pitching moments were evaluated from measurements of the pressure reactions on the tunnel walls of the forces on the airfoil. Drag forces were determined from wake-survey measurements made with a rake of total-head tubes.

RESULTS AND DISCUSSION

Section lift, drag, and quarter-chord pitching-moment coefficients are presented as functions of Mach number at constant angles of attack in figures 3, 4, and 5, respectively, for the NACA 0010-1.50 40/1.051 airfoil section. Corrections for tunnel-wall interference by the methods of reference 3 have been applied to the data. The results shown as dashed portions of the curves should be used with caution because of the possible influence of wind-tunnel choking effects in this region.

Lift Characteristics

The variation of lift coefficient with angle of attack at constant Mach number is shown in figure 6 for the NACA 0010-1.50 40/1.051 airfoil section. Maximum lift coefficient as a function of Mach number is presented in figure 7 for leading-edge radii of 1.50, 1.10, 0.70, and

0.27 percent of the chord, respectively. The variation of lift-curve slope with Mach number is presented in figure 8 for the various leading-edge radii.

Lift-divergence Mach number as a function of lift coefficient is presented in figure 9 for the leading-edge radii investigated. Although little change in the Mach number for lift divergence at low and moderate lift coefficients is observed for a leading-edge-radius variation from 1.10 to 0.27 percent of the chord, an increase of approximately 0.02 Mach number at low lift coefficients is noted for the leading-edge radius of 1.50 percent of the chord.

Drag Characteristics

Drag coefficient as a function of lift coefficient at constant Mach number is shown in figure 10 for the NACA 0010-1.50 40/1.051 airfoil section. A peculiar trend in the drag polars is observed at Mach numbers above 0.8. At Mach numbers above 0.825, figure 4 shows that the drag coefficients at 0° and 1° are essentially the same. This unusual characteristic has been observed in low-speed tests of airfoils having large leading-edge radii. It has been attributed to the fact that the pressure gradient on one surface becomes less adverse as the lift coefficient is varied from zero, increasing the relative extent of laminar flow on this surface with consequent reduction in drag.

The variation of drag-divergence Mach number with lift coefficient is presented in figure 11 for the various leading-edge radii. At small to moderate lift coefficients, the drag-divergence Mach number increases with increases in leading-edge radius.

Pitching-Moment Characteristics

Pitching-moment coefficient as a function of lift coefficient at constant Mach number is presented in figure 12 for the NACA 0010-1.50 40/1.051 airfoil section.

CONCLUSIONS

Comparison of the results of a wind-tunnel test at high subsonic Mach numbers of a 10-percent-thick, symmetrical modified NACA four-digit-series airfoil section having a leading-edge radius of 1.50 percent of the chord with previously determined results for the same basic airfoil section with leading-edge radii of 1.10, 0.70, and 0.27 percent of the chord indicate but two principal effects of leading-edge radius:

1. The Mach number for lift divergence for the airfoil with the largest leading-edge radius is approximately 0.02 higher at low lift coefficients than for the other airfoils.

2. The Mach number for drag divergence is generally increased at low and moderate lift coefficients with increasing leading-edge radius.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., July 9, 1953

REFERENCES

1. Summers, James L., and Graham, Donald J.: Effects of Systematic Changes of Trailing-Edge Angle and Leading-Edge Radius on the Variation with Mach Number of the Aerodynamic Characteristics of a 10-Percent-Chord-Thick NACA Airfoil Section. NACA RM A9G18, 1949.

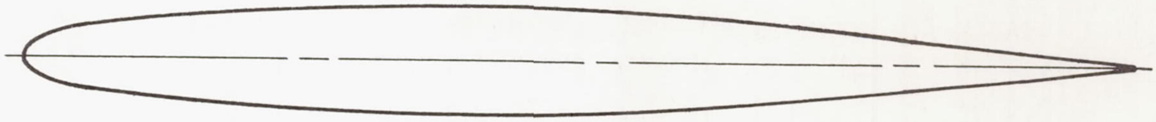
2. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA Rep. 824, 1945.

3. Allen, H. Julian, and Vincenti, Walter G.: Wall Interference in a Two-Dimensional-Flow Wind Tunnel, with Consideration of the Effect of Compressibility. NACA Rep. 782, 1944.

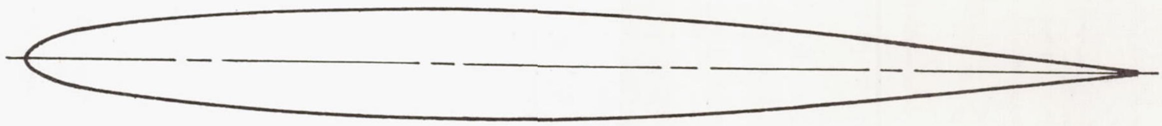
TABLE I.- COORDINATES FOR THE NACA 0010-1.50 40/1.051 AIRFOIL SECTION

[Stations and ordinates in percent of airfoil chord]

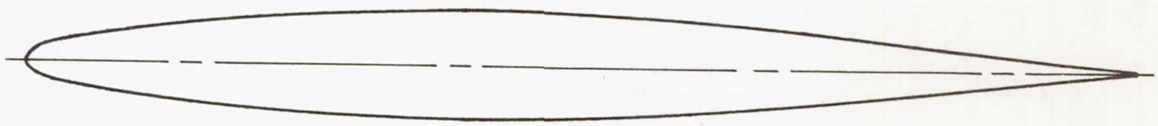
Station	Upper or lower surface ordinate
0	0
.5	1.110
.75	1.328
1.25	1.653
2.50	2.183
5.00	2.805
7.50	3.203
10	3.500
15	3.948
20	4.295
25	4.577
30	4.798
40	5.000
50	4.783
60	4.197
70	3.338
80	2.305
90	1.193
95	.638
100	.100
L.E. radius: 1.50-percent chord	



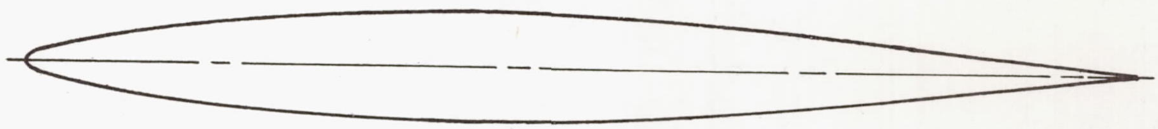
NACA 0010-1.50 40/1.051 airfoil section



NACA 0010-1.10 40/1.051 airfoil section



NACA 0010-0.70 40/1.051 airfoil section



NACA 0010-0.27 40/1.051 airfoil section

Figure 1.- Influence of leading-edge radius on profile shape.

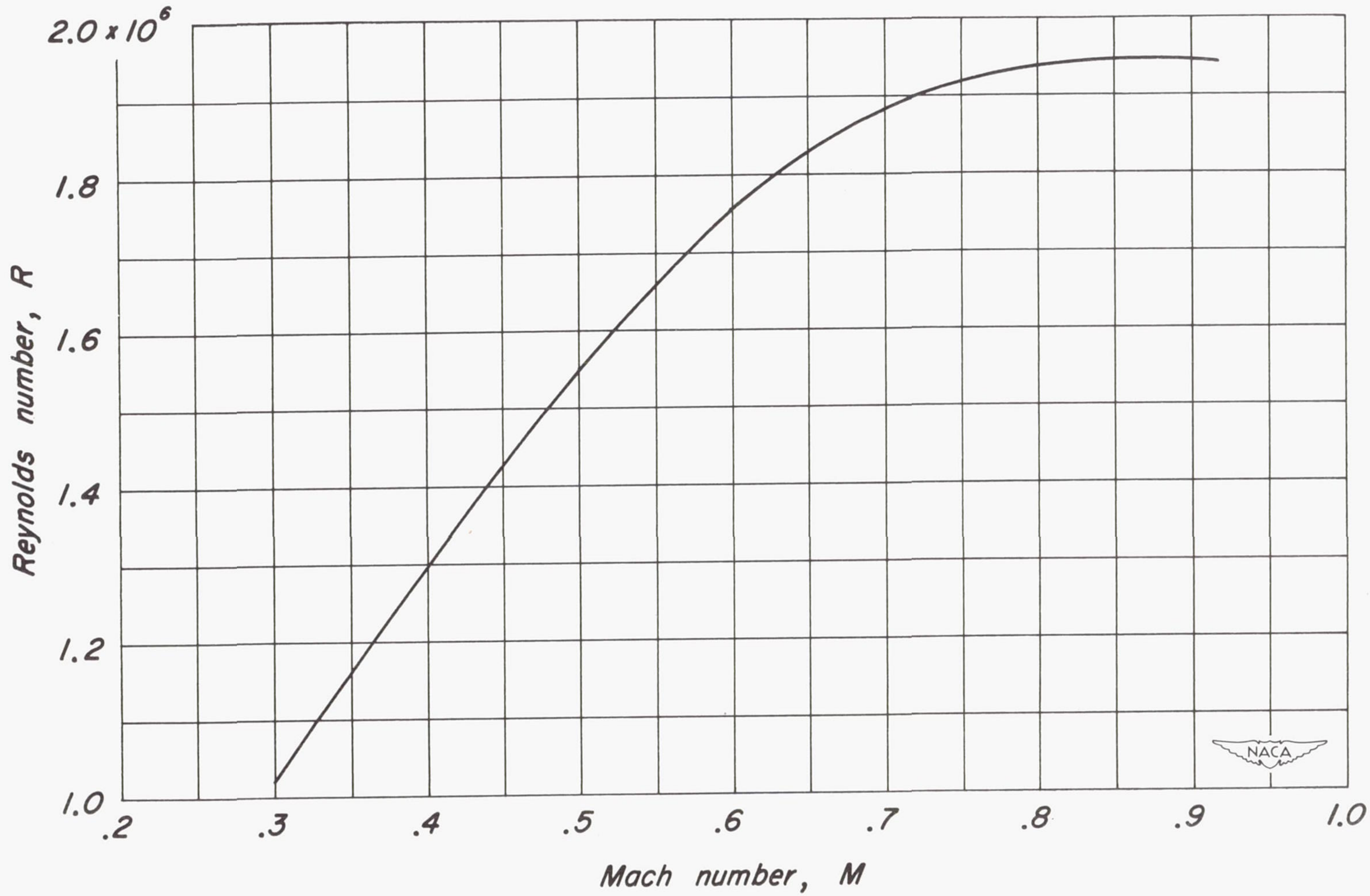


Figure 2.– Variation of Reynolds number with Mach number for 6-inch-chord airfoils in the Ames 1-by $3\frac{1}{2}$-foot high-speed wind tunnel.

2D

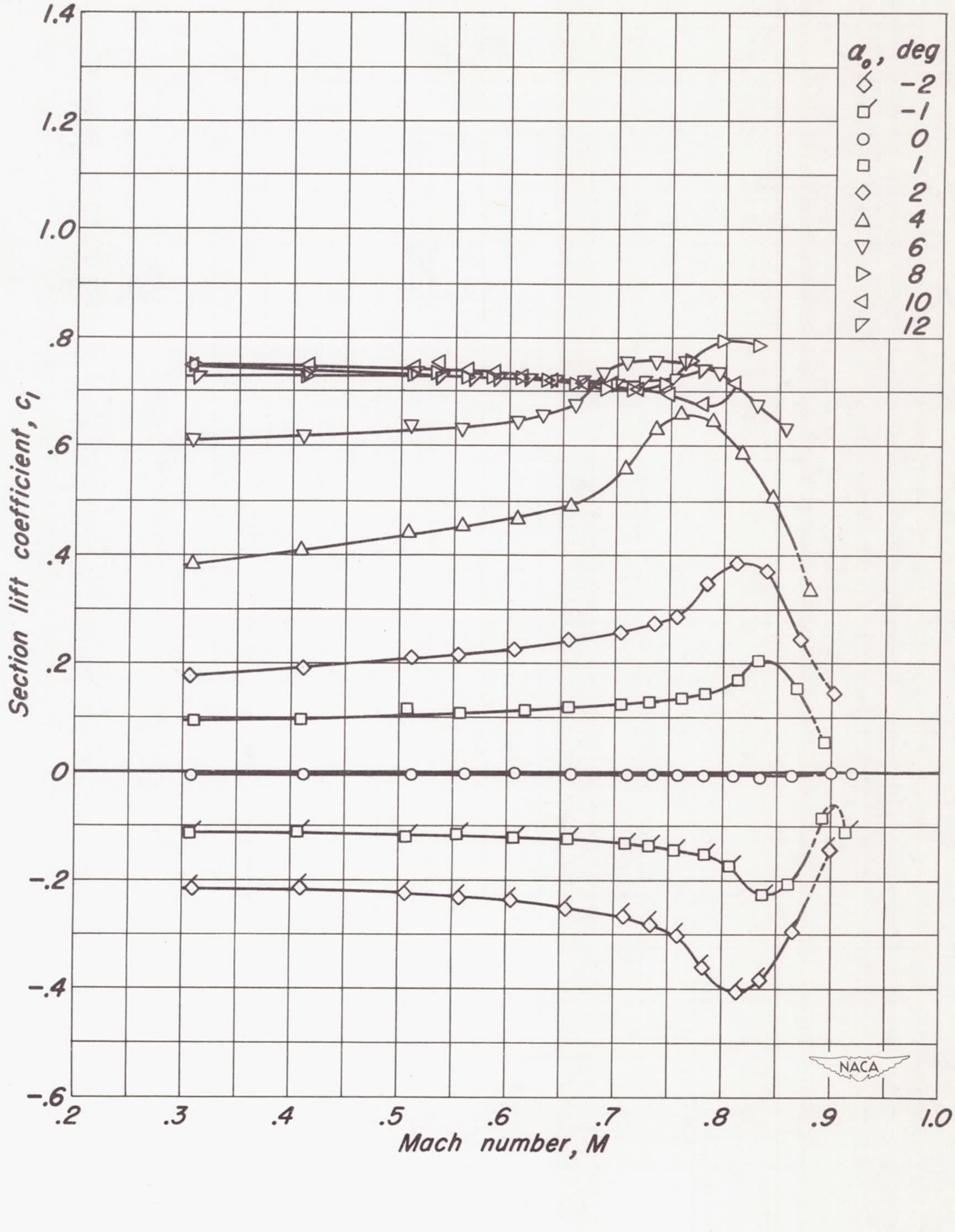


Figure 3.- Variation of section lift coefficient with Mach number for the NACA 0010-1.50 40/1.051 airfoil section at constant section angles of attack.

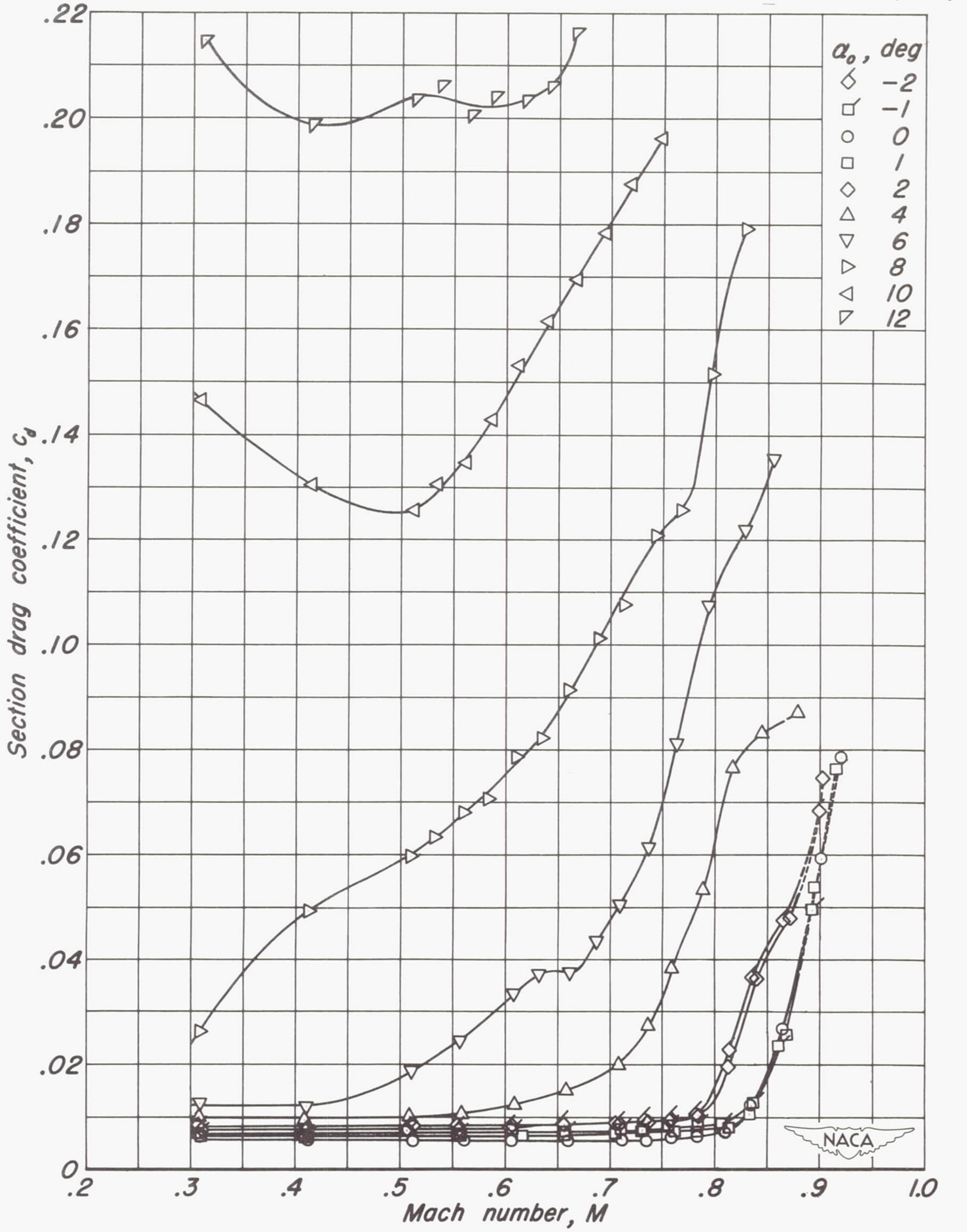


Figure 4.- Variation of section drag coefficient with Mach number for the NACA 0010-1.50 40/1.051 airfoil section at constant section angles of attack.

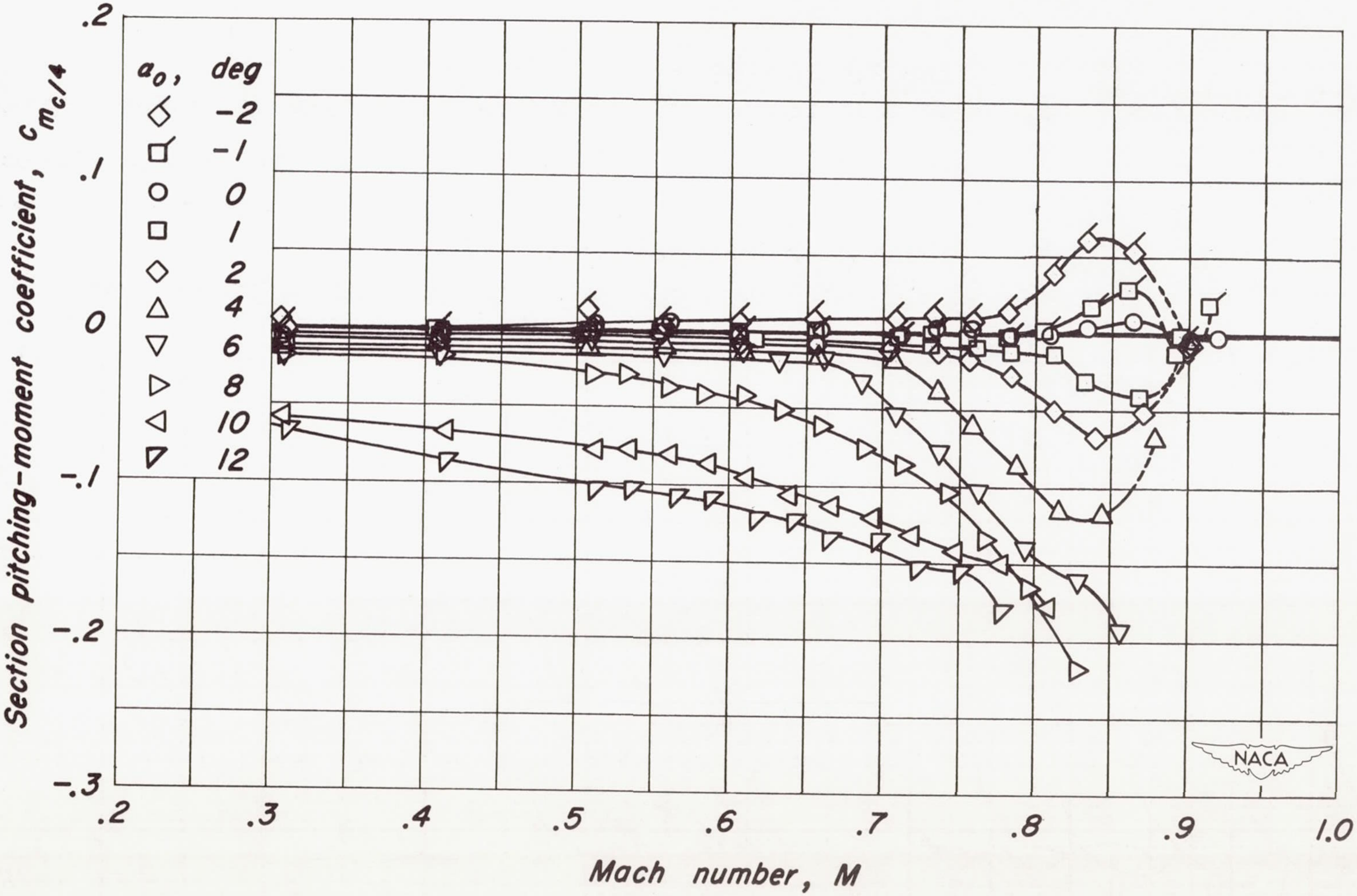


Figure 5.- Variation of section pitching-moment coefficient with Mach number for the NACA 0010-1.50 40/1.051 airfoil section at constant section angles of attack.

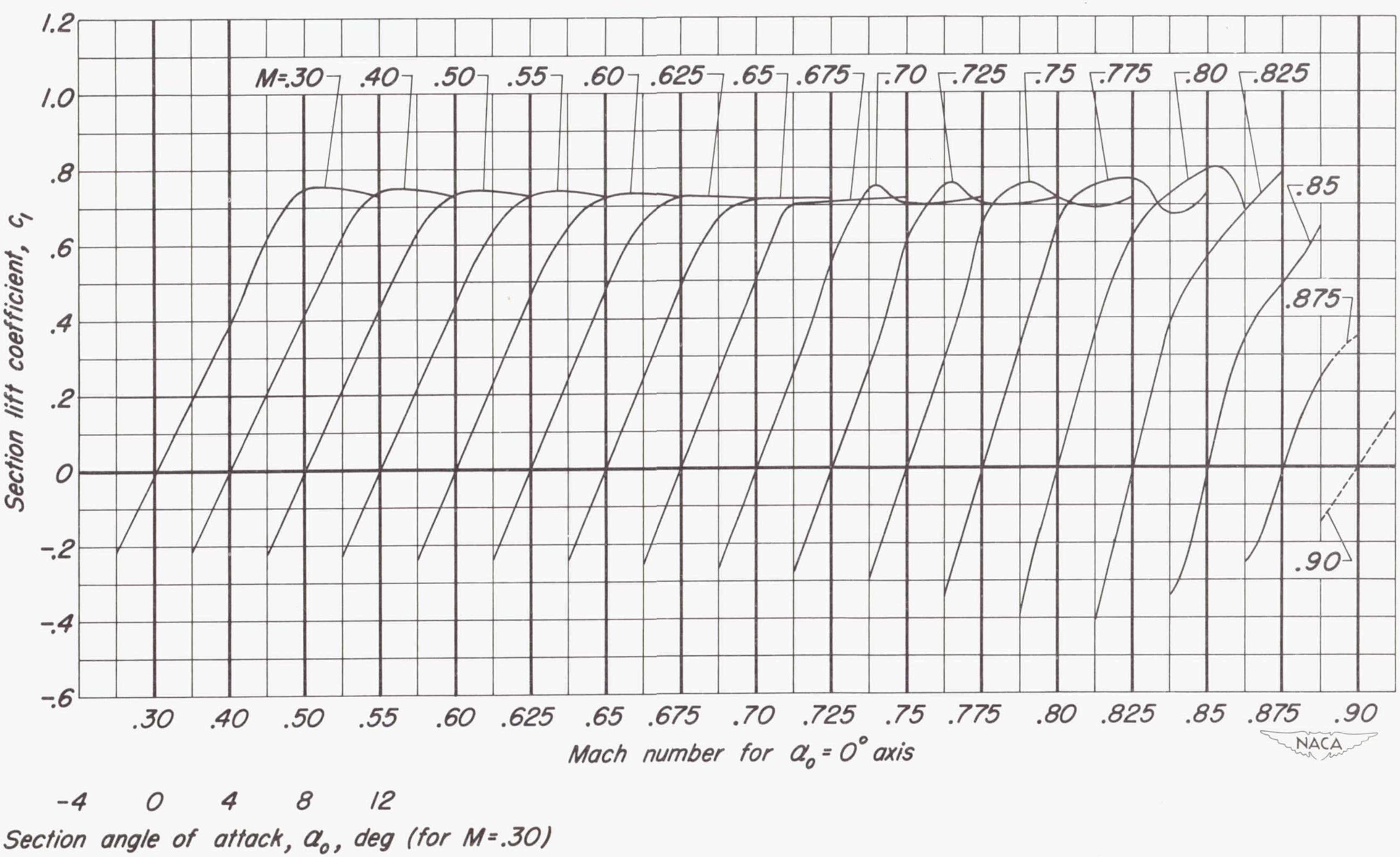


Figure 6.- Variation of section lift coefficient with section angle of attack for the NACA 0010-1.50 40/1.051 airfoil section at various Mach numbers.

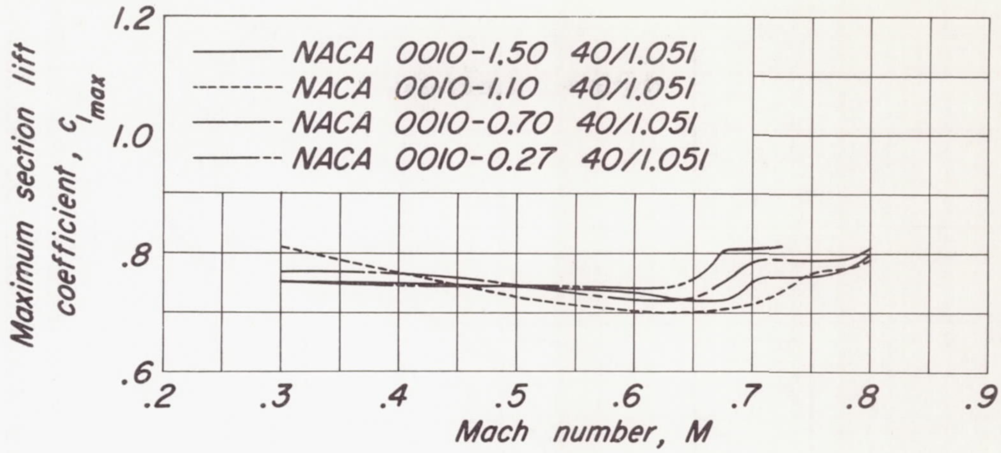


Figure 7.- Effect of leading-edge radius on the variation of maximum section lift coefficient with Mach number.

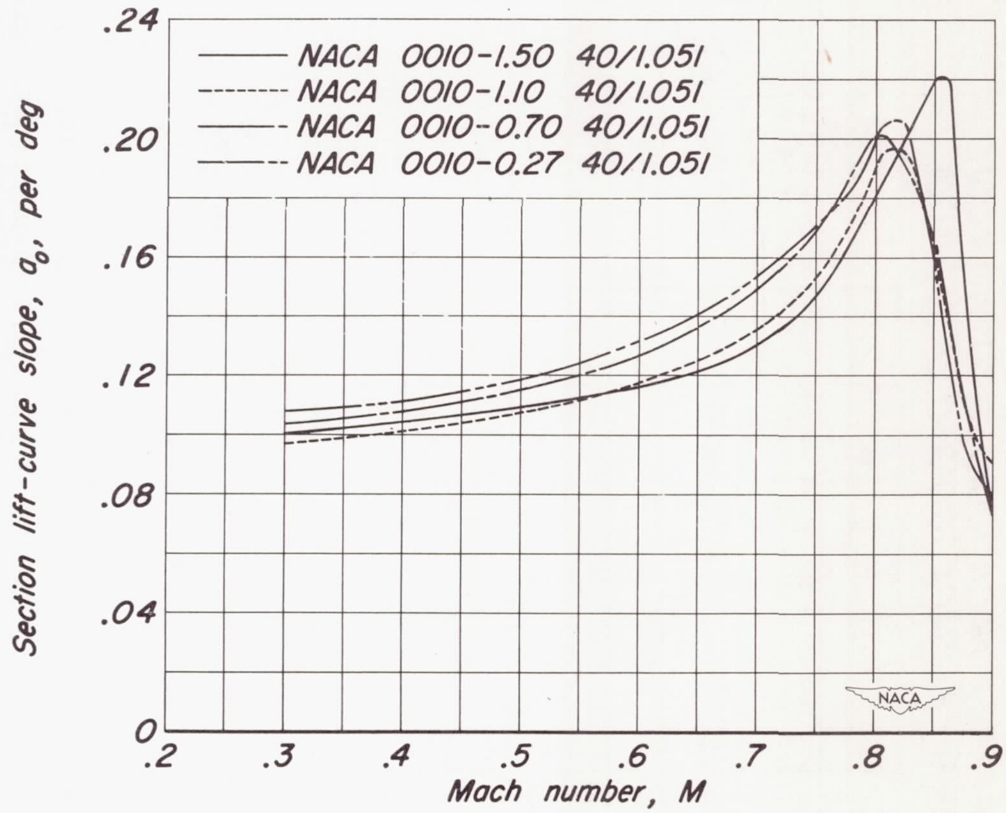


Figure 8.- Effect of leading-edge radius on the variation of section lift-curve slope with Mach number.

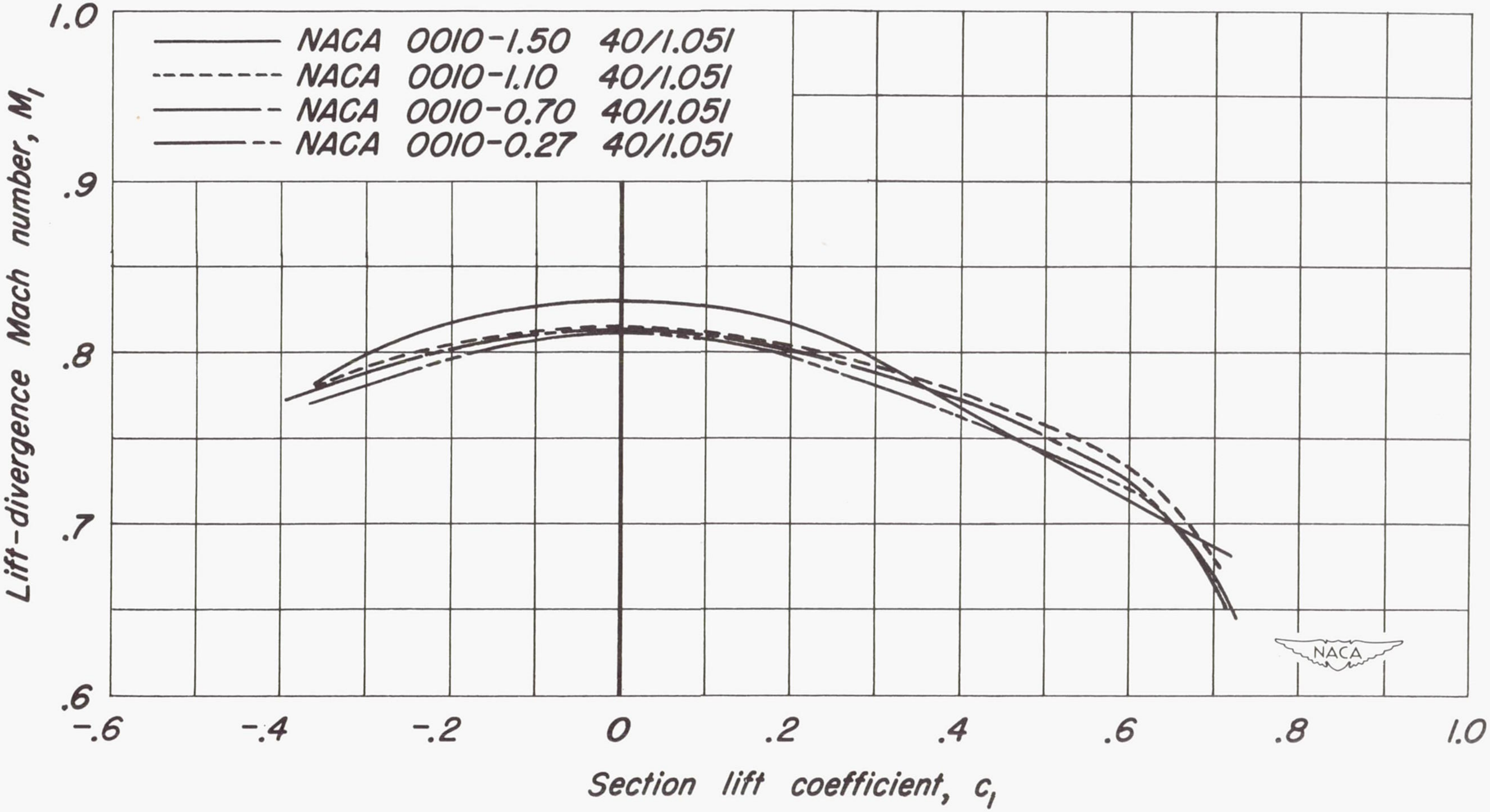
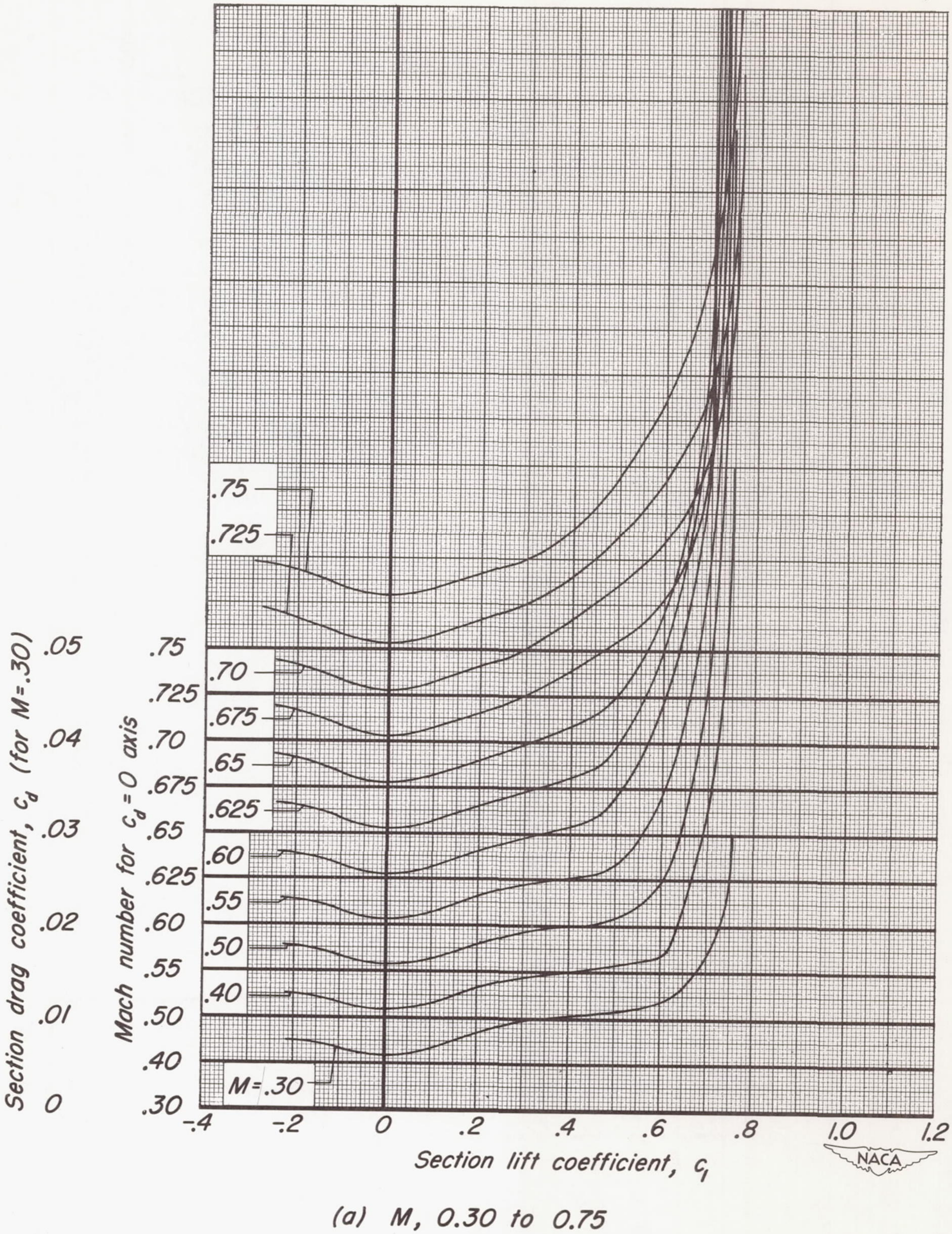
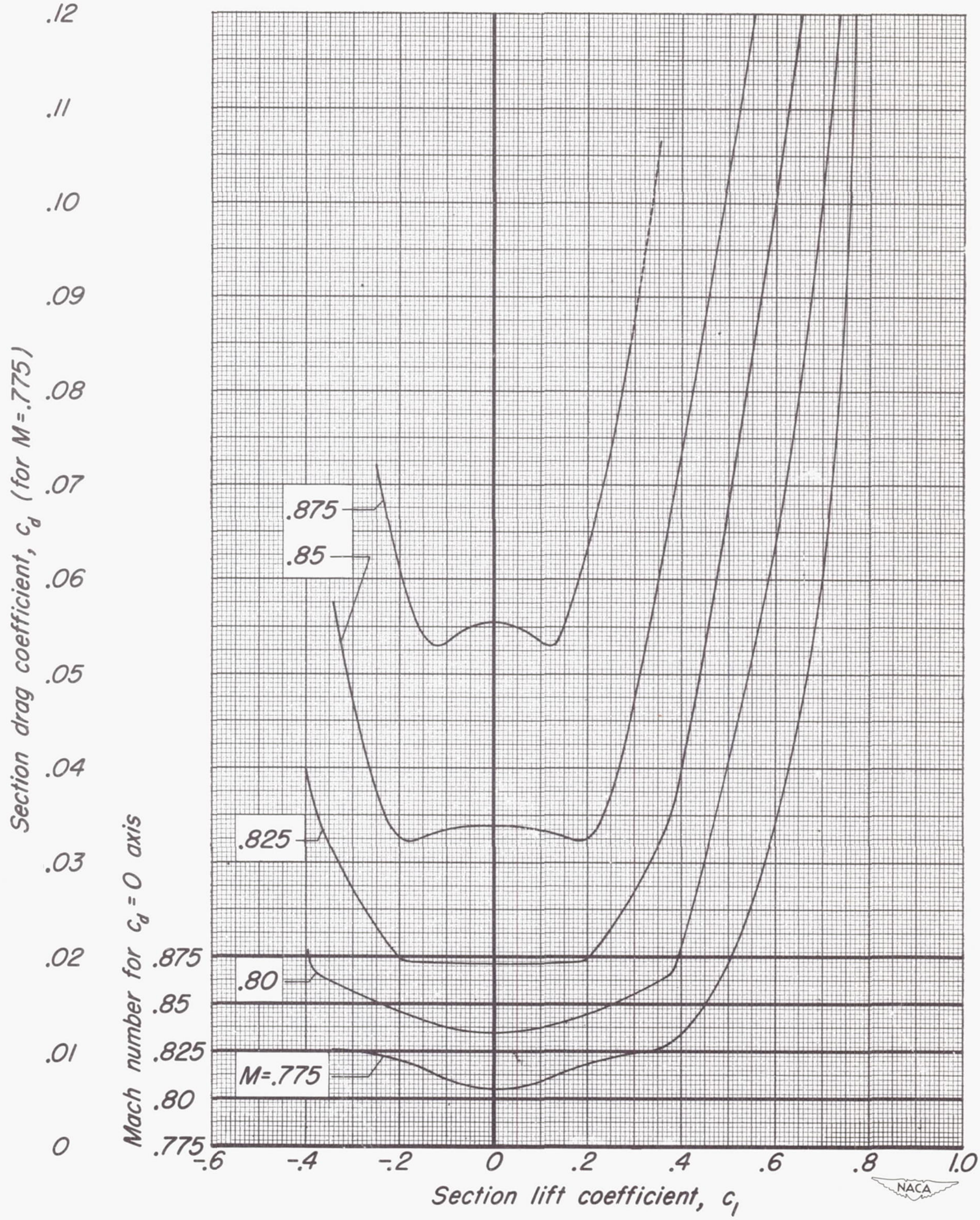


Figure 9.- Effect of leading-edge radius on the variation of lift-divergence Mach number with section lift coefficient.



(a) M, 0.30 to 0.75

Figure 10.- Variation of section drag coefficient with section lift coefficient for the NACA 0010-1.50 40/1.051 airfoil section at various Mach numbers.



(b) M, 0.775 to 0.875

Figure 10.- Concluded.

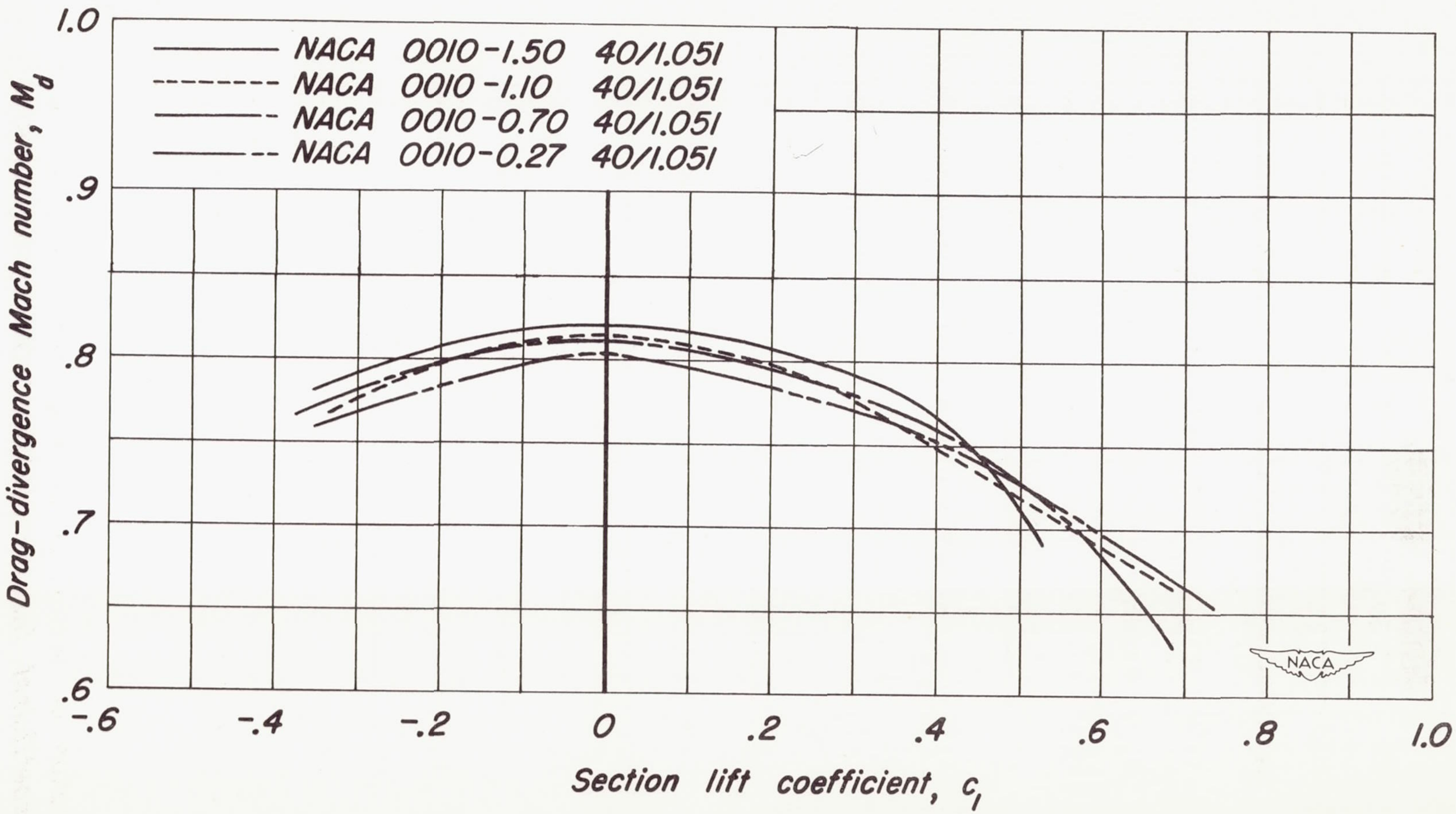


Figure 11.- Effect of leading-edge radius on the variation of drag-divergence Mach number with section lift coefficient.

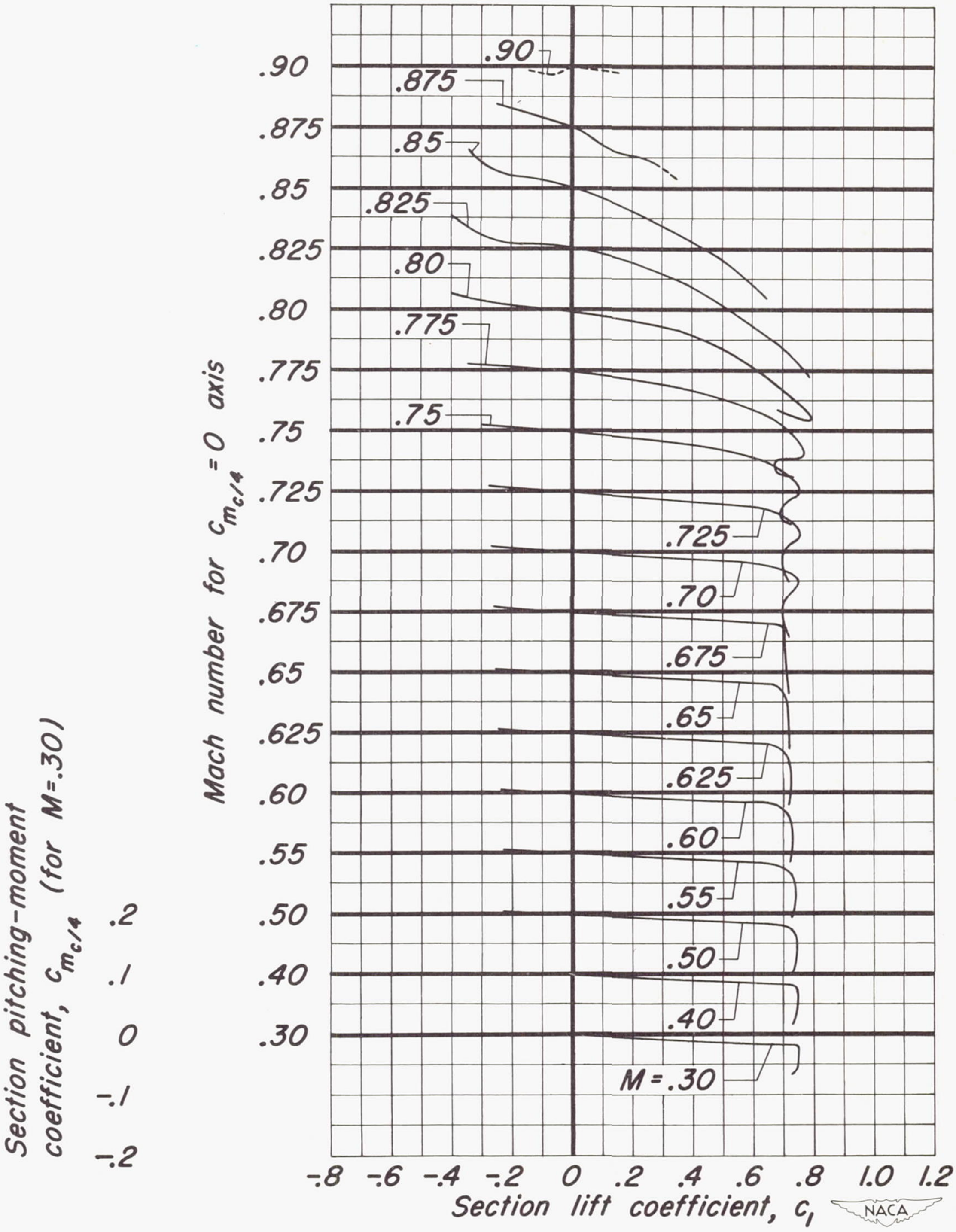


Figure 12.- Variation of section pitching-moment coefficient with section lift coefficient for the NACA 0010-1.50 40/1.051 airfoil section at various Mach numbers.